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SNR G292.2−0.5: A Radio Supernova Remnant Associated with the Young Pulsar J1119−6127

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Abstract. We report on Australia Telescope Compact Array observations in the direction of the young high-magnetic-field radio pulsar PSR J1119−6127. In the resulting images we identify a non-thermal radio shell of diameter 15′, which we classify as a previously uncataloged young supernova remnant (SNR), G292.2−0.5. This SNR is positionally coincident with PSR J1119−6127, and we conclude that the two objects are physically associated. No radio emission is detected from any pulsar wind nebula (PWN) associated with the pulsar; our observed upper limits are consistent with the expectation that high-magnetic-field pulsars produce radio nebulae which fade rapidly. This system suggests a possible explanation for the lack of associated radio pulsars and/or PWNe in many SNRs.

1. Introduction: PSR J1119−6127

PSR J1119−6127 is a 408-ms pulsar with a large inferred surface magnetic field strength ($B \sim 4 \times 10^{13}$ G) which was discovered in the Parkes Multibeam Pulsar Survey (Camilo et al. 2000). A measured $\dot{P}$ and $\ddot{P}$ for the pulsar indicates an age of $\tau = 1.7 \pm 0.1$ kyr (assuming an initial spin period $P_0 \ll P$), making this the youngest pulsar discovered in the survey. Despite its similarity in age to the Crab pulsar, PSR J1119−6127 has significantly different characteristics, most notably its much larger period and magnetic field. Since it is young, PSR J1119−6127 is a good candidate to have an associated supernova remnant (SNR) and pulsar wind nebula (PWN). These can be detected and studied using radio imaging.

2. Radio Imaging of PSR J1119−6127 with ATCA

We have observed the region containing PSR J1119−6127 with the Australia Telescope Compact Array (ATCA) radio interferometer. Both 1.4 and 2.5 GHz data were taken using pulsar gating, and data were combined from multiple array configurations. A 1.4 GHz total intensity map is shown in Figure 1. A limb-brightened radio shell of $\sim 15'$ diameter is evident, which we call G292.2−0.5. Using a spectral tomography technique to compare the flux in the 1.4 and 2.5 GHz maps (Katz-Stone & Rudnick 1997; Crawford 2000), we measured a spectral index for the brightest part of the shell of $\alpha = -0.6 \pm 0.2$ ($S \sim \nu^{\alpha}$). Off-pulse maps from pulsar gating indicate no detectable PWN emission coincident with the pulsar. We quantified these upper limits by adding synthetic PWNe of varying sizes and fluxes to the data prior to mapping to determine the threshold of detectability. No polarization information from the observations could be used owing to uncorrectable instrumental leakage from bright nearby HII regions.

3. Results

3.1. G292.2−0.5: A New Shell SNR

The measured $\alpha = -0.6 \pm 0.2$ for the shell indicates a non-thermal (synchrotron) origin for the radio emission, which is expected for a SNR. There is no significant infrared emission coincident with the shell, and the observed spectral index is consistent with those measured for other young shell SNRs (Table 1). We conclude from this evidence that G292.2−0.5 is a previously uncataloged radio shell SNR.

3.2. An Association Between PSR J1119−6127 and SNR G292.2−0.5

The circular, limb-brightened morphology of the SNR (Figure 1) is expected for a young SNR which has not yet been deformed by the interstellar medium (e.g., Cas A, Kepler) and suggests the SNR is young. The location of PSR J1119−6127 at the center of shell is also consistent with an association with the pulsar: the probability of a chance alignment within $1'$ of the shell center is estimated to be $\lesssim 10^{-4}$. This positional coincidence is also consistent with the youth of the pulsar. If the pulsar were born at the shell center, then the implied

transverse velocity is reasonable ($v_{\rm PSR} \lesssim 500$ km s^{-1}) for a 5 kpc SNR distance. The implied shell size in this case is $R_{\rm shell} \sim 10$ pc, and for an assumed SNR age of $\tau = 1.7$ kyr, this corresponds to a free expansion velocity of $v_{\rm shell} \sim 6000$ km s^{-1}. These $R_{\rm shell}$ and $v_{\rm shell}$ values are consistent with other SNR shells of similar age (Table 1). From this evidence, we conclude that PSR J1119−6127 and SNR G292.2−0.5 are physically associated.

3.3. Absence of an Observable PWN

We can use the observed upper limits on PWN emission to test an evolutionary model of PWNe proposed by Bhattacharya (1990). Qualitatively, the model suggests that a high-magnetic-field pulsar born spinning rapidly undergoes severe magnetic braking at early times. The bulk of the rotational energy of the pulsar is quickly deposited into the nebula, and the pulsar cannot continue to significantly power the PWN at later times. The PWN rapidly fades from expansion losses and is not detectable at $\tau \sim 2$ kyr, while the pulsar has slowed to a much longer period. We have derived a scaling formula for the predicted surface brightness Σ of a PWN powered by PSR J1119−6127 which includes many assumptions (Reynolds & Chevalier 1984; Crawford et al. 2001 and references therein). Using this formula, we have scaled the observed Crab nebula surface brightness to obtain a predicted value for PSR J1119−6127 of $\Sigma \sim 6 \times 10^{-22}$ W m^{-2} Hz^{-1} sr^{-1} at 1 GHz, which is well below our sensitivity limits. There is a strong dependence of Σ on PWN age in the model, and our upper limits indicate that if $P_0 \gtrsim 200$ ms for PSR J1119−6127 (corresponding to $\tau \lesssim 1.2$ kyr), the PWN would be detectable in our observations. The absence of a detectable PWN argues in favor of $P_0 \lesssim 200$ ms for PSR J1119−6127 and supports the evolutionary model of Bhattacharya (1990).

Table 1. Young Shell SNR Parameters.

SNR	Other Name	τ (kyr)	$R_{\rm shell}$ (pc)	$v_{\rm shell}$ (km s^{-1})	$\alpha_{\rm shell}$
1987A		0.01	~ 0.2	~ 18000	−0.9
G111.7−2.1	Cas A	0.3	2.04	6700	−0.77
G4.5+6.8	Kepler	0.4	1.92	4700	−0.64
0540−69.3		0.8	7.27	9100	−0.41
G29.7−0.3	Kes 75	~ 1	~ 8	~ 8000	−0.7
G320.4−1.2	MSH 15−52	1.7	~ 20	~ 11500	−0.5
G292.2−0.5		**1.7**	**$\sim$ 10**	**$\sim$ 5900**	**−0.6**
G332.4−0.4	RCW 103	~ 2	~ 5	~ 2500	−0.5
G260.4−3.4	Puppis A	3.7	35.2	9300	−0.5

4. Conclusions

Using ATCA radio imaging observations, we have discovered G292.2−0.5, a previously unknown shell SNR with a diameter of 15′ and a circular, limb-brightened morphology. Evidence strongly suggests that the SNR is associated with the young high-magnetic-field pulsar PSR J1119−6127. We have detected

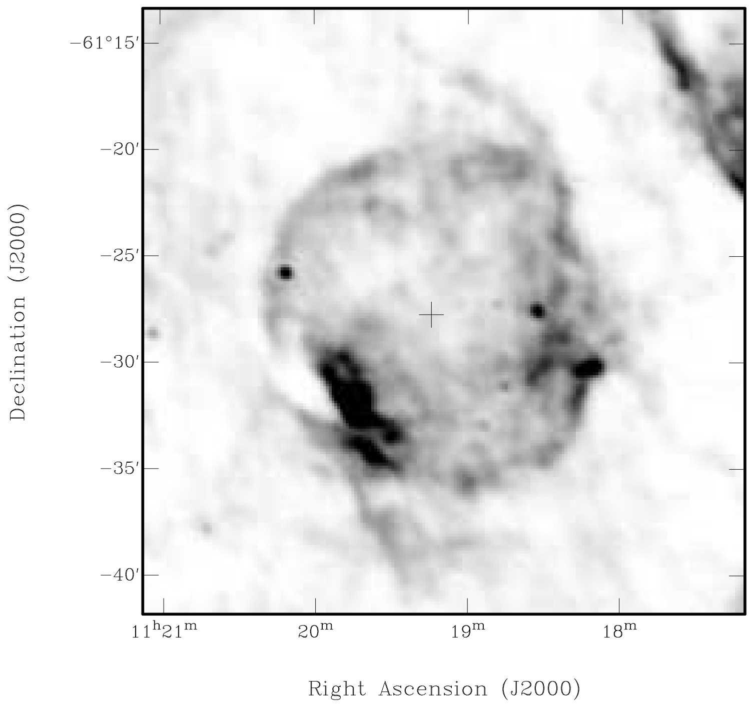

Figure 1. 1.4 GHz total intensity ATCA image of the shell SNR G292.2−0.5 using all baselines shorter than 7.5 kλ. The position of PSR J1119−6127 is indicated by the cross. No radio PWN is evident.

no PWN powered by PSR J1119−6127 and have quantified the upper limits on PWN radio emission. Our upper limits support a model of PWNe powered by high-magnetic-field pulsars and indicate $P_0 \lesssim 200$ ms for PSR J1119−6127. These results may provide an explanation for the absence of detected radio pulsars and PWNe in many shell SNRs: shells might contain high-magnetic-field pulsars which are faint or beaming away and do not power observable PWNe. However, this explanation depends upon the feasibility of a large population of young high-magnetic-field pulsars. A more complete and detailed treatment of the work described here is presented in Crawford et al. (2001).

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